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Sprites, their relationship to intense quasi-electrostatic thundercloud field and the physical mechanisms for their production

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Abstract : In this paper, observational reports on high altitude flashes and their mysterious characteristics are critically examined. Results obtained from electromagnetic observations in conjunction with the intense thunderclouds are pointed out and the possible consequences are discussed.

Keywords : Atmospherics, sprites, thundercloud

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High altitude flashes and bursts called sprites are extremely mystifying to scientists all over the globe, and very little is understood about them. Several ideas have already been suggested to explain this unusual phenomenon. However, the observations are yet too scarce and their nature is still confusing. In our restless atmosphere, these flashes may even cause hazards to high-flying aircraft and satellites. A large number of ghost-like intense optical flashes appear during electrical storms much above thunderstorm clouds in the mesosphere and stratosphere. The satellite launched to test nuclear blasts detected radio flashes which are, in general, 10,000 times more intense than the radio signals normally generated by lightning [1]. Sprites are rather exceptional electromagnetic events. The mesoscale connective system (MCS) is an unusual meteorological phenomenon. Some of the interesting results are presented in this communication and the results have been interpreted from a consideration of possible physical connections including MCS.

Pilots and others have reported [1] seeing coloured columns of light above tropospheric thunderclouds for years (Figure 1). To the eye, they resemble material ejected from a very high explosive source, something like the tracks of atomic particles or rays in a cloud chamber. The flashes may sometimes be described as carrot-, tumip- or jelly fish shaped, while at some other times they have an unusual appearance of dazzling arrays of fireworks which seem to dance for milliseconds sufficiently above the cloud top. The unusual flashes over intense thunderstorms, appear in two distinctly different forms : (a) Blood red flashes may be called sprites and (b) blue jets appearing in narrow beams. The flashes last only a few thousandths of a second and extend upto about 90 km height, *i.e.*, at the bottom of the ionosphere.

Recently, the space shuttle in one of its flights [2] recorded 18 such flashes over Australia, Africa, South and North America. To capture the position and altitude of the flashes special low-light-level cameras were used in aircraft and were recorded on colour video.

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(i) "Red sprites" are mesospheric, striated glows that typically recur at intervals of several minutes over mature and dissipating organized convection [3–6]. They have been documented over the stratiform regions of mid-latitude mesoscale connective systems [7] (MCSs).

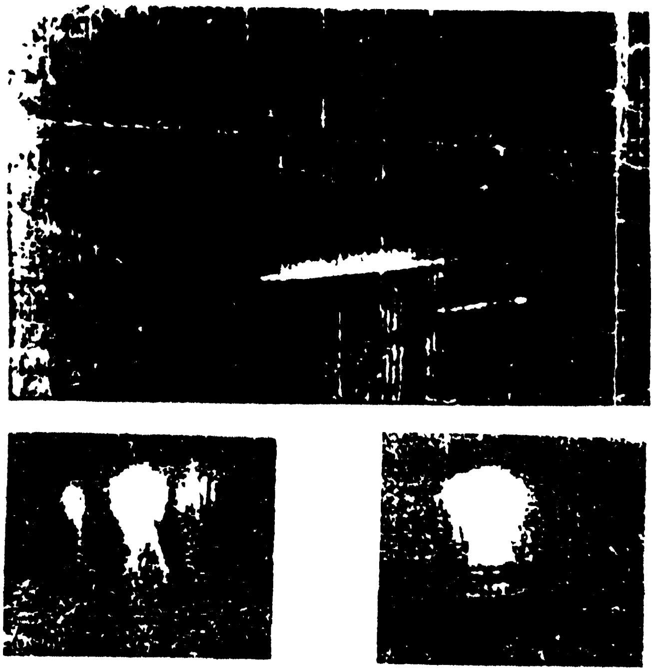

Figure 1. Photograph of some typical unusal flashes as reported both in stratosphere and mesosphere, much above the tropospheric thunderclouds [1].

(ii) Sprites tend to occur in clusters, sometimes appearing to follow the horizontal progression of in-cloud lightning. Compared to the typical MCS lightning flash rates of 40 to 50 per minute [8] sprites are infrequent, although not rare occurrences.

(iii) In MCSs, cloud-to-ground (CG) lightning occurs in a "horizontal dipole" pattern [9–11], with negative strokes occurring in areas of active convection and positive strokes dominant in the stratiform regions. These positive CG strokes are infrequent, but they frequently exhibit large peak return stroke currents [12] and may lower tens to hundreds of coulombs of charge to ground. In most of cases, they are associated with horizontal extensive "spider lightning" discharges with characteristic long dendritic channels that may finger for many tens of kilometers along the cloud base [13–15].

(iv) Positive CG strokes are disproportionately associated with electromagnetic "Q-burst" events in the extremly low frequency (ELF) Schumann resonance (SR) band, the large amplitude ringing of the entire Earth-ionosphere cavity [16]. The SR "Continuous" spectra are believed to be driven by the integrated effects of all global lightning. The Q-bursts, separated in time by minutes to hours, are assumed to be excited by the largest lightning events on the planet [17,18].

(v) The combined data of sprites and ELF transients provide confirmation of their overall coincidence [19] For example, the time of the first video detection of a sprite, is found to coincide with the ELF transient's onset to within a few milliseconds (Figure 2). The time of an associated positive ground stroke, having a peak current of 327 KA, is also shown in the figure The coincidence of sprites with ELF transients implying extraordinarily large charge transfer favours an electrostatic over an electromagnetic triggering mechanism [20].

Some observations have reported that sprites are caused by the radiated electromagnetic fields associated with

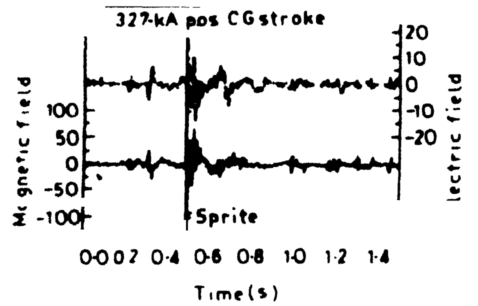

Figure 2. Record showing sprite related ELF transient [19]. The electric and magnetic fields (in arbitrary units) are represented by thin and bold marking respectively The times of positive CG strokes and sprites are overlaid

the charge acceleration in intracloud flashes [21] or return strokes.

Some recent observations show a distinctive form of sprites associated with positive CG flashes carrying currents of about 23 to 100 kA in mesoscale thunderstorms. These sprites are characterized by long vertical columns about 10 km long, less than 1 km in diameter and exhibit practically no variation in brightness along their length. On some occasions 'columniform' sprites (c-sprites) reveal a dominant form of sprite activity above a thunderstorm [22].

In Kalyani (22°58' N, 88°28' E), we have been engaged in studying atmospherics in the VLF band at 10, 21 and 27 kHz. The required modifications in the receivers have been made to accommodate a large dynamic range of field intensities. Atmospherics originating in thundercloud-associated lightning discharges show a spectral plak [23] at about 10 kHz, while the characteristics of high altitude discharges are yet to be confirmed. In audio monitoring arrangement for listening to atmospherics we recorded radio noise coinciding with severe thundercloud and lightning (as confirmed by Radar observation) in the form of a distinct 'pop' when played back through a speaker. In fact, on some of the occasions the 'pop' sound noted had a particular characteristics that sharply differed from normal lightning discharge signals. This 'pop sound was reported by Sentman and his group [4] at the University of Alaska where electromagetic observations were taken along with the luminous observations. In our case also, the electromagnetic observations are to be supplemented by the luminous observations, or some suitable improved techniques need to be imposed in order to distinguish the observations which are associated with the sprites.

From high-flying aircraft observations, it has been confirmed that the red ones called sprites reach a height of about 90 km above the top of the storm clouds, while the blue ones have an entirely different structure, usually narrowly collimated sprays of light in the form of fans that propagate at a speed of 100 km/s. The electrical fields so generated by lightning, can propagate upwards through the stratosphere and mesosphere and rip off electrons from the molecules there [2]. It is further assumed that a single powerful cosmic ray particle may collides with an air molecule in the stratosphere or mesosphere and starts off a runaway breakdown. Electric field soundings through MCS stratiform anvils indicate a strong layered charge structure, which includes concentrated positive charge near the 0°C isotherm [24]. The observed charge densities and altitudes and inferred changes in the total dipole moment support the fact that the positive CG strokes must be trapping a horizontal region of ~150 km^2, either through long horizontal channels or through a really extensive dendrites [25]. Both the configurations are favourable for electrostatically stressing the mesosphere to breakdown and excite large amplitude ELF transients (Figure 3). Rapidly,

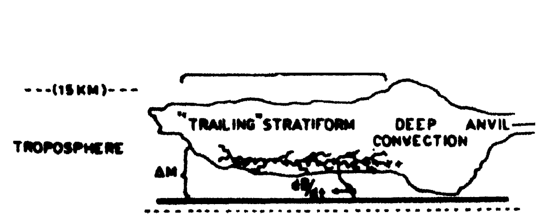

Figure 3. Schematic diagram showing the proposed connections among sprites, positive CG strokes and Q-bursts. The positive CG stroke assumed to be the electrostatic source for the sprites and electromagnetic source for the Q-burst. Radiation upon ground attachment of the CG stroke is represented by dB/dt while the change in the total dipole moment ΔM from the event excites Q bursts at ELF in the earth-ionosphere cavity.

the return stroke delivers negative charge through an existing extensive dendritric structure near the base of the cloud. It is reasonable to assume that the change in the total dipole moment (Δm) from the event excites resonant Q bursts in the earth-ionosphere cavity. In fact, the electromagnetic transients of largest amplitude at ELF are Q bursts and sprite-producing positive ground flashes appear to be sources for Q bursts [4,19].

As the mesospheric (electrostatic) breakdown favours rapid charge transfer, one may assume that the majority of the total charge transfer is occurring within a few milliseconds of the stroke's ground attachment than that associated with slow (~100 ms) processes in a long continuing current later in the flash. Thus, the return stroke would rapidly progress into existing dendrites aloft. However, this behaviour is inconsistent with the recent observation that positive return stroke progression does not decelerate with hight [26]. Also, the brightest illumination of positive return stroke channels aloft lasts for several milliseconds, and upto 50% of the total field change of positive flashes occurs during the first few milliseconds of the return stroke initiation [27].

The results we have reported here are preliminary and more observations are required to get a better understanding of the phenomena. Such observations should be coordinated with other groups where facilities of both video and radio wave observations from the ground are available. We believe that ultraviolet and infrared studies would give deeper insight into the problem. A model may possibly explain emissions in the optical radio and γ-ray regions. Further measurements of high bandwidth waveform of sprite-related ground strokes and air-craft observations of electric fields above stratiform anvils are needed from further informations.

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